A Study of the Behavior of the Brittle Lacquer Commercially Known as Stresscoat When Subjected to Biaxial Stress of a Known Intensity and Configuration

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Supervisor: W. M. Murray

January 16, 1948

Cambridge, Massachusetts
January 16, 1948

Professor J. S. Newell,
Secretary of the Faculty,
Massachusetts Institute of Technology,
Cambridge, Massachusetts .

Dear Sir:

In accordance with the requirements for the Degree of Master of Science in Naval Construction and Engineering, we submit herewith a thesis entitled "A Study of the Behavior of the Brittle Lacquer Commercially Known as Stresscoat When Subjected to Biaxial Stress of Known Intensity and Configuration."

Respectfully,

A STUDY OF THE BEHAVIOR OF THE BRITTLE LACQUER COMMERCIALLY KNOWN AS STRESSCOAT WHEN SUBJECTED TO BIAXIAL STRESS OF A KNOWN INTENSITY AND CONFIGURATION

By

Arthur E. Francis
Lieutenant, U.S.Navy
M.E., Stevens Institute
of Technology, 1942

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Submitted in partial fulfillment of the

requirements for the degree of

MASTER OF SCIENCE IN NAVAL CONSTRUCTION AND ENGINEERING

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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ACKNOWLEDGEMENT

The authors wish to express their appreciation and indebtedness to the following persons:

To Professor William M. Murray for the suggestion of the specific problem and for guidance during the investigation.

To Mr. W. L. Walsh for instruction in Stresscoat and strain gauge technique and for practical assistance rendered during the investigation.

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E - Average longitudinal strain determined from several calibration bars, micro inches/inch.

E_m - Young's Modulus.

t - Time of loading specimen, seconds.

T_d - Temperature of coating surface during test, deg. F.

S# - Number of particular grade of Stresscoat used.

D - Deviation or $E - E_{max}$, micro inches/inch.

%D - Percent deviation or $(100)\ (E - E_{max}) / (E_{max})$, %.

$\%D_s$ - Percent stress deviation, $(S_{bar} - S_{max})\ (100)/S_{max}$.

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v_o - Poisson's ratio of steel on which strain gauges were calibrated, .285.

k - A constant with value of .021 for type A-3 strain gauges.

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Results

It was found that more strain was required to produce a crack pattern under tensile load than was indicated by the calibration bar. The opposite effect was observed when the specimen was subjected to internal pressure. The presence of crazing decreased the sensitivity of Stresscoat. The presence of a strain crack pattern in one direction has a yet unexplained effect on the sensitivity of Stresscoat to failure in a perpendicular direction.

Object

The purpose of this investigation was to expand the limited knowledge of the behavior of Stresscoat when subjected to a biaxial stress condition different from that stress condition existing in the calibration bar and to correlate the information obtained in such a manner that more precise quantitative determinations are possible. For the benefit of future experimenters in this field an attempt was made to analyze any peculiarities in the behavior of the Stresscoat which were observed.

Procedure

The actual strain on the surface of a hollow cylindrical test specimen was determined with strain gauges when the surface of the vessel was subjected to different combinations of two-dimensional strain. These combinations of strain were produced by applying axial loading and internal pressure to the specimen. The strains causing a crack

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pattern in the Stresscoat applied to the test specimen in the vicinity of the strain gauges were compared with the strains indicated by the calibration bars.

Conclusion

The deviation between actual strain and the strain indicated by the Stresscoat may vary from zero to thirty percent depending upon the ratio of minimum strain to the maximum strain in the specimen. When strain, indicated by Stresscoat, is used to calculate stress the deviation between actual stress and calculated stress is reduced to a maximum value of approximately fifteen percent.

Recommendations

Further investigation of the behavior of Stresscoat should be conducted under controlled atmospheric conditions. Apparatus should be designed by which axial load and internal pressure may be applied uniformly and simultaneously to the specimen, to facilitate handling the creep characteristic of Stresscoat at all values of S_{min}/S_{max}. Evaluation of Poisson's ratio and the modulus of elasticity of Stresscoat, combined with the values of strain for various values of S_{min}/S_{max} would allow the determination of the theory of failure of Stresscoat.

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INTRODUCTION

Stresscoat is the latest widely known development in the field of brittle coatings used for stress-strain analysis of the component parts of structures. When a base material is subjected to a progressively increasing stress, the distortion in the base material will eventually cause any brittle coating adhering to its surface to fail by cracking. In most coats these cracks occur in a direction perpendicular to the direction of the principal stress. If the base material is subjected to such large stresses that its yield point is exceeded and very large amounts of distortion occur, the brittle coating will flake or spawl off. One of the early observed instances of this phenomenon was the cracking or flaking off of mill scale on structural members under load. The places in the structure where this breakdown of scale first occurred were points of weakness or stress concentration. Early investigators also noticed that the presence of a coat of white-wash on structural members increased the ease with which a failure in the mill scale could be observed. Cracking and spawling of bitumastic enamel used on shipboard was another early example of this phenomenon. Attempts to utilize these observations for quantitative measurements were unsuccessful.

The search for a brittle coating which would be capable of dependable quantitative, as well as qualitative, interpretation continued in the United States and other countries (principally Great Britain and Germany). Many substances

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The search for a brittle coating which would be capable of dependable quantitative, as well as qualitative, interpretation continued in the United States and other countries (principally Great Britain and Germany). Many investigators such as sugar, sulphur, plaster of Paris, and various resins were tried. The late Professor A. V. DeForest of Massachusetts Institute of Technology did considerable prelininary work which contributed to the final development of the present day Stresscoat. He tried various methods of coating application as well as types of material for the coating itself. The methods of application investigated were:

<u>a.</u> Covering the surface with powdered material which was subsequently heated until it melted to form a continuous coat.

<u>b.</u> Brushing, dipping, or spraying the molten coating on the base material.

<u>c.</u> Brushing, dipping, or spraying the coating, dissolved in a solvent which evaporates as the coating assumes its brittle condition.

Mr. Greer Ellis (8) in 1937 determined the composition of a brittle lacquer having those characteristics which made it ideal for qualitative and quantitative strain indicating. The desirable characterists are:

<u>a.</u> Ability to fail by cracking due to strains within the elastic range of most engineering materials.

<u>b.</u> Crack sensitivity fairly independent of coat thickness.

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d. Patterns of cracks [illegible] easily discernible.

This brittle lacquer is currently known, commercially, as Stresscoat. It is manufactured and distributed by the Magnaflux Corporation. It is excellent for qualitative experimentation and the manufacturer claims that quantitative results obtained from tests conducted under controlled loading and atmospheric conditions are accurate within about 10%.

A calibration bar is employed to interpret the results obtained when using Stresscoat. The bar is secured at one end only in a jig so that it approximates a cantilever beam. The specimen under investigation and the calibration bar are sprayed and dried under identical conditions. After drying, the specimen is stressed and the free end of the calibration bar is depressed a known amount in the jig. This produces a known stress and strain in the bar varying from zero at the free end to a maximum value at the fixed end. Cracks appear in the Stresscoat over that portion of the bar in which the strain exceeds the value which will cause failure in the particular coating involved. Current practice is to assume that the strain under the last crack toward the free end of the bar is the same strain which exists under the first crack to appear in the Stresscoat on the specimen. The validity of this assumption is open to question because the calibration bar is subjected to uniaxial stress with a constant ratio between the principal strains produced; while a material under investigation may be subjected to any of an unlimited number of biaxial stress conditions, each causing a particular combination of two or three dimensional strains.

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Only a limited amount of work investigating the behavior of Stresscoat under biaxial stress has been done and very little has been published. Eric Olsen (11) in 1941 investigated the accuracy of quantitative Stresscoat determinations when the specimen was subjected to a two-dimensional strain condition different from that existing in the calibration bar for a few specific two-dimensional strain conditions. It is the aim of this report to further develop the investigation in this field by conducting enough consecutive tests in each of a few particular conditions of two-dimensional strain so that some knowledge of the magnitude of the deviation between the calibration bar indicated strain and the actual strain in the specimen may be learned.

During the course of the experiments various peculiarities of the general behavior of Stresscoat were observed. Although this information was secondary to the original purpose of the investigation it has been recorded and discussed because it was felt that it may be of value to those who will continue with further work in this field.

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PROCEDURE

The first step in the investigation was to select a test specimen in which at least two different conditions of biaxial stress could be set up. The specimen used was a thin walled tube of low carbon steel which was made into a pressure vessel by welding forged plugs into each end. The outboard ends of these plugs were machined to fit a self centering attachment on the tensile testing machine used. The end plugs were drilled and tapped to receive high pressure copper tube and fittings for applying the internal pressure to the test specimen. Four SR-4 electric strain gauges were affixed at equal intervals around the outside of the tube far enough from the ends to eliminate end effects. Two of these strain gauges were circumferential and two were axial. The gauges in the same direction were placed on opposite sides of the specimen. The dimensions and composition of the specimen were chosen to give strains applicable to Stresscoat investigation, within the elastic limits of the material and the capacity of the loading devices.

The second step was the mastery of Stresscoat and strain gauge technique. About six weeks were consumed before it was felt that enough proficiency had been gained in applying Stresscoat, controlling conditions during the drying and testing, and observing the first cracks to produce reliable data. During the early part of this educational period, an attempt was made to learn by experience, but the

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Anticipation of atmospheric conditions, which would exist twelve to twenty-four hours after the application of the coat, was required in choosing the proper grade of lacquer. The grade chosen should fail at a practical value of strain, but should not be so sensitive as to craze during the drying period. The choice was made with the aid of a chart provided by the manufacturer. Difficulty was encountered in obtaining sufficient sensitivity for the tensile runs without the occurrence of crazing due to the large and rapid fluctuation of the temperature in the Institute during the night. This problem was defeated by covering the specimen and calibration bars with a large cardboard enclosure during the drying period. A lighted electric bulb inside this enclosure served to keep the coatings at a sufficiently high temperature to prevent crazing. Several times it was necessary to artificially cool the coatings in order to obtain cracking at a practical value of strain. The specimen detailed informations published by the manufacturer (13) were carefully studied prior to taking the data incorporated in this report. Such a course was considered to be most conducive to observing as many of the characteristics of [illegible] as possible. The [illegible] was limited to a special spray booth in the basement of the Institute and the drying took place in the [illegible] Memorial Trust Laboratory. The pressure runs were also made in the stress Laboratory, but the tensile runs were made in the [illegible] Testing Laboratory of the Institute.

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The pressure runs were made with the specimen freely supported by the ends in a wooden cradle. The hydraulic pump, used to supply the water pressure internally to the specimen, was of the jack type. It was equipped with a pressure gauge which allowed a rough estimate of the internal pressure, and also permitted us to control the rate of load application. The tensile or axial loading runs were made by pulling the specimen in a conventional tensile and the calibration bars were maintained at the same constant temperature during each test.

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A total of twenty-seven runs were made on the test specimen, but the data of runs seventeen through twenty-seven was considered to be that which represented the best technique, and consequently only these eleven runs were used.

It was considered of interest to investigate the effect of the presence of severe crazing on the behavior of the Stresscoat. An experiment was attempted using six calibration bars, three of which were artificially crazed by exposure to a low temperature for a short period of time, while the other three were maintained with a clear coat. The bending test was applied to these bars after all six of them had returned to the same temperature and had remained at that temperature for about one-half of an hour. Time loading of these bars was used because the progress of the cracks could be followed on the crazed bars with more ease and accuracy than would be the case if a one second load were applied.

After each tensile crack pattern had been formed on the specimen, and an interval of time exceeding twice the time during which the load was applied and held had elapsed, the specimen was subjected to a pressure run. The results testing machine. The pressure gauge and the beam balance readings were not essential to the data as the strain gauges provided the actual strains on the surface of the specimen. It was necessary to correct for lateral sensitivity of the SR-4 strain gauges.

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An investigation of the conformance of the calibration bar to beam theory and Poisson's ratio effect was made by checking the lateral strain at various points along the bar with SR-4 strain gauges.

The strain gauge readings and axial load or internal pressure at the appearance of the first crack in the coating on the specimen were recorded. The strain corresponding to the last crack on the calibration bars was taken as the calibrating strain. A flash light focused perpendicular to the anticipated direction of the cracks was a necessary aid in catching the first crack. The actual strains were compared with those indicated by the calibration bar. The deviations of the calibration bar strain from actual strain for the pressure and tensile runs were compared. For the tests involving the calibration bars alone the results occurring of these runs indicated the desirability of further investigation of the nature of cracking of Stresscoat in a direction perpendicular to cracks already produced on the specimen by a previous test. Therefore, a fifteen inch square of celluloid one-eighth of an inch thick was coated with Stresscoat. After drying, this flat plate was secured by one edge in a cantilever fashion and the opposite edge was depressed a certain distance in a given length of time. After allowing time for the creep recovery of the Stresscoat, the plate was turned ninety degrees and the identical experiment was repeated. The nature of the total crack pattern was then observed.

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For a detailed description of the equipment used see Appendix A.

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RESULTS

Table I

Internal Pressure Applied to Cylindrical Specimen

Run No.	E_a	E_c	$\frac{E_{min}}{E_{max}}$	E	D	%D	t	T_d	#Stress-coat
17	206	835	.247	900	65	78	225	66.0	1204
18	197	780	.252	953	173	22.2	120	70.5	1204
19	130	443	.293	490	47	10.6	40	73.5	1206
20	203	830	.245	852	22	2.7	50	71.5	1205
21	200	894	.224	984	90	10.1	60	71.0	1205
Average value:			.252			10.6			

Table II

Axial Tensile Load Applied to Cylindrical Specimen

Run No.	E_a	E_c	$\frac{E_{min}}{E_{max}}$	E	D	%D	t	T_d	#Stress-coat
23	638	-195	-.325	450	-187	-29.2	70	70.5	1207
24	652	-175	-.268	595	- 57	- 8.8	65	76.0	1208
27	642	-182	-.284	580	- 62	- 9.6	55	74.0	1207
Average value:			-.293			-15.9			

Table III

Axial Tensile Load Applied to Cylindrical Specimen
(Stresscoat on Specimen was Crazed)

Run No.	E_a	E_c	$\frac{E_{min}}{E_{max}}$	E	D	%D	t	T_d	#Stress-Coat
25	568	-179	-.315	560	-8	-1.4	35	76.5	1208
26	675	-185	-.284	600	-75	-11.1	50	75.5	1208
Average value:			-.300			-6.2			

Table IV

Internal Pressure Applied To Cylindrical Specimen After Crack Pattern Had Been Formed By Tensile Load.

Run No.	E_a	E_c	$\frac{E_{min}}{E_{max}}$	E	D	%D	t	T_d	#Stress-coat
23a	134	592	.227	510	-82	-13.8	25	70.5	1207
24a	138	606	.228	590	-16	- 2.6	25	76.0	1208
27a	170	637	.267	545	-92	-14.4	35	74.0	1207
Average value:			.241			-10.2			

Table V

Internal Pressure Applied To Cylindrical Specimen After Crack Pattern Had Been Formed By Tensile Load.
(Stresscoat On Specimen Was Crazed)

Run No.	E_a	E_c	$\frac{E_{min}}{E_{max}}$	E	D	%D	t	T_d	#Stress-coat
25a	140	512	.273	560	48	9.4	28	76.5	1208
26a	131	633	.207	608	-25	-4.0	35	75.5	1208
Average value:			.240			2.7			

Table VI

Investigation Of Crazing And Its Effect On The Sensitivity Of Stresscoat As Applied To The Calibration Bars.

Bar No.	Condition of Coat	Sensitivity 10^{-6} in/in.	Time Sec.	Temp. Fah.
1	clear	680	30	72.5
2	clear	620	30	72.5
3	clear	630	30	72.5
4	crazed	780	30	72.5
5	crazed	820	30	72.5
6	crazed	850	30	72.5
7	clear	700	30	72.5
8	clear	630	1	72.5
9	clear	620	1	72.5
10	clear	600	1	72.5

Table VII

Summary of Biaxial Stress Conditions

$\frac{E_{min}}{E_{max}}$	$\frac{E_{min}/E_{max}}{e/E}$	S_{min}/S_{max}	%D	$\%D_s$	Run
-1.0	3.39	-1.0	-24.4*	- 1.9	Torsion
-0.295	1.00	0.0	-15.9	-15.9	Tension
0.25	-0.849	0.5	10.6	- 6.1	Cylinder
1.0	-3.39	1.0	29.0*	- 9.9	Sphere

$e/E = -.295/1 = -.295$

* From Olsen's (11) data.

RESULTS

(1) When perpendicular strains are in the ratio of 4 to 1, about 10% less strain is required to produce a crack pattern on the specimen than was indicated by the calibration bars. (See Table I)

(2) When perpendicular strains are in the ratio of 3.4 to -1, about 16% more strain was required to produce a crack pattern on the specimen than was indicated by the calibration bars. (See Table II)

(3) The presence of crazing in the Stresscoat prior to straining the coat to failure has a definite effect other than that of making the crack pattern difficult to observe.

   a. Tests with several calibration bars indicate that the presence of crazing decreases the sensitivity of the coat about 25%. (See Table VI)

   b. Actual experiments with the specimen indicate that crazing does decrease the sensitivity, however, too few experiments have been conducted to give an approximate percentage decrease in sensitivity. (See Table III and Table V)

(4) The presence of strain cracks in one direction prior to straining the coat to failure in a perpendicular direction has a definite effect on the sensitivity of the Stresscoat.

   a. When perpendicular strains are in a ratio of 4 to 1 and straining to failure has been previously obtained

RESULTS

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(2) When perpendicular strains are in the ratio of 3.4 to -1, about 15% more strain was required to produce a crack pattern on the specimen than was indicated by the calibration bars. (See Table II)

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a. Tests with several calibration bars indicate that the presence of crazing increases the sensitivity of the coat about 25%. (See Table I)

b. Actual experiments with the specimen indicate that crazing does decrease the sensitivity, however, too few experiments have been conducted to give an approximate percentage decrease in sensitivity. (See Table III and Table V)

(4) The presence of strain cracks in one direction prior to straining the coat to failure in a perpendicular direction has a definite effect on the sensitivity of the stresscoat.

a. When perpendicular strains are in a ratio of 4 to 1 and straining to failure has been previously obtained

(4a) cont'.

in the minor direction, it has been found that about 10% more strain is required to produce a crack pattern on the specimen than was indicated by the calibration bars. (See Table IV)

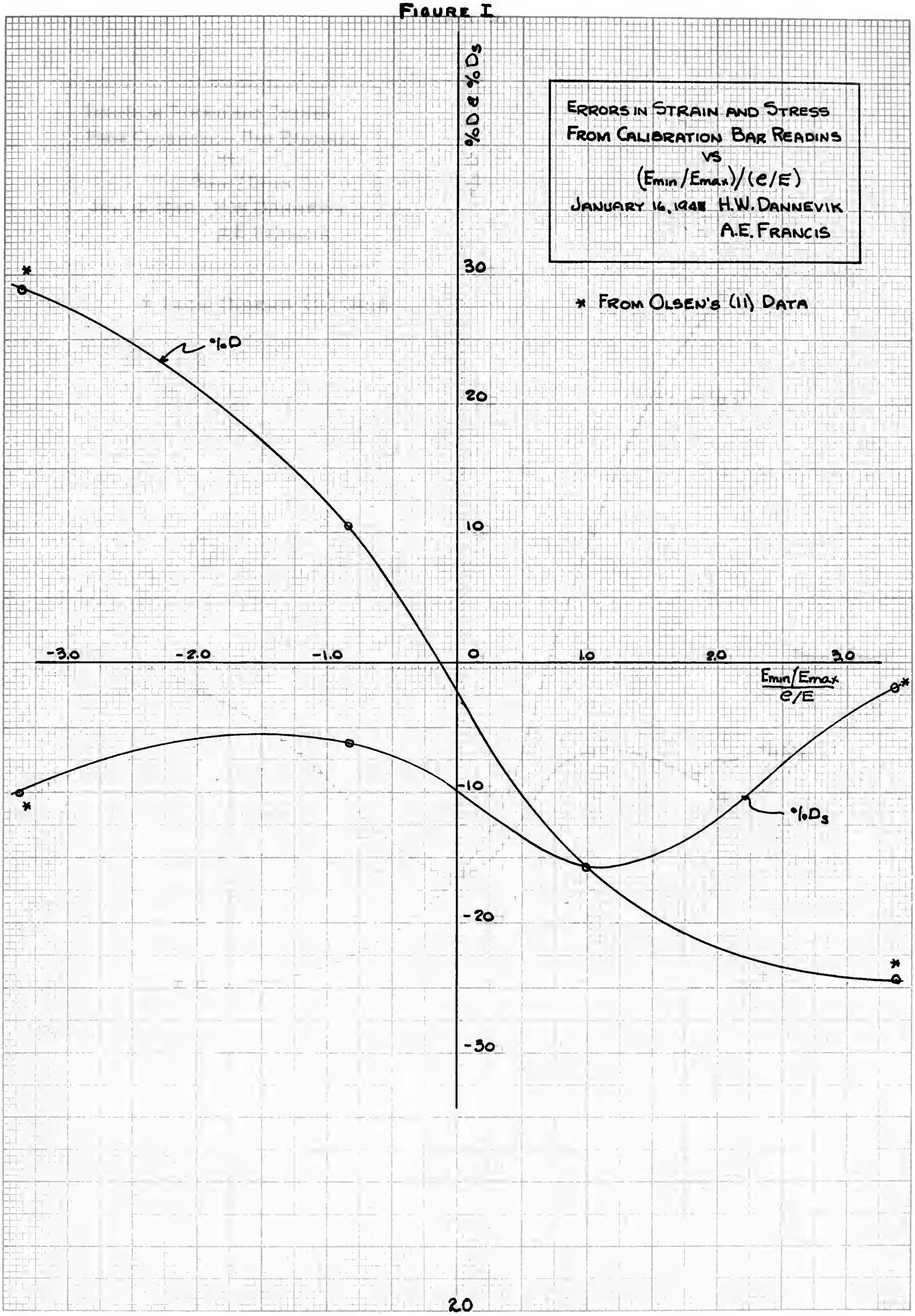
b. Experiments, conducted with a 15 inch square piece of celluloid loaded as a cantilever beam to a certain deflection in one direction and then to the same deflection in the same length of time in a direction perpendicular to the first test, indicated that a crack pattern in one direction had little if any effect on the formation of a crack pattern at right angles to the original pattern. Of four tests made in this manner every one indicated identical sensitivity in either direction.

(4a) cont'.

in the minor direction, it has been found that about 10% more strain is required to produce a crack pattern on the specimen than was indicated by the calibration bars. (See Table IV)

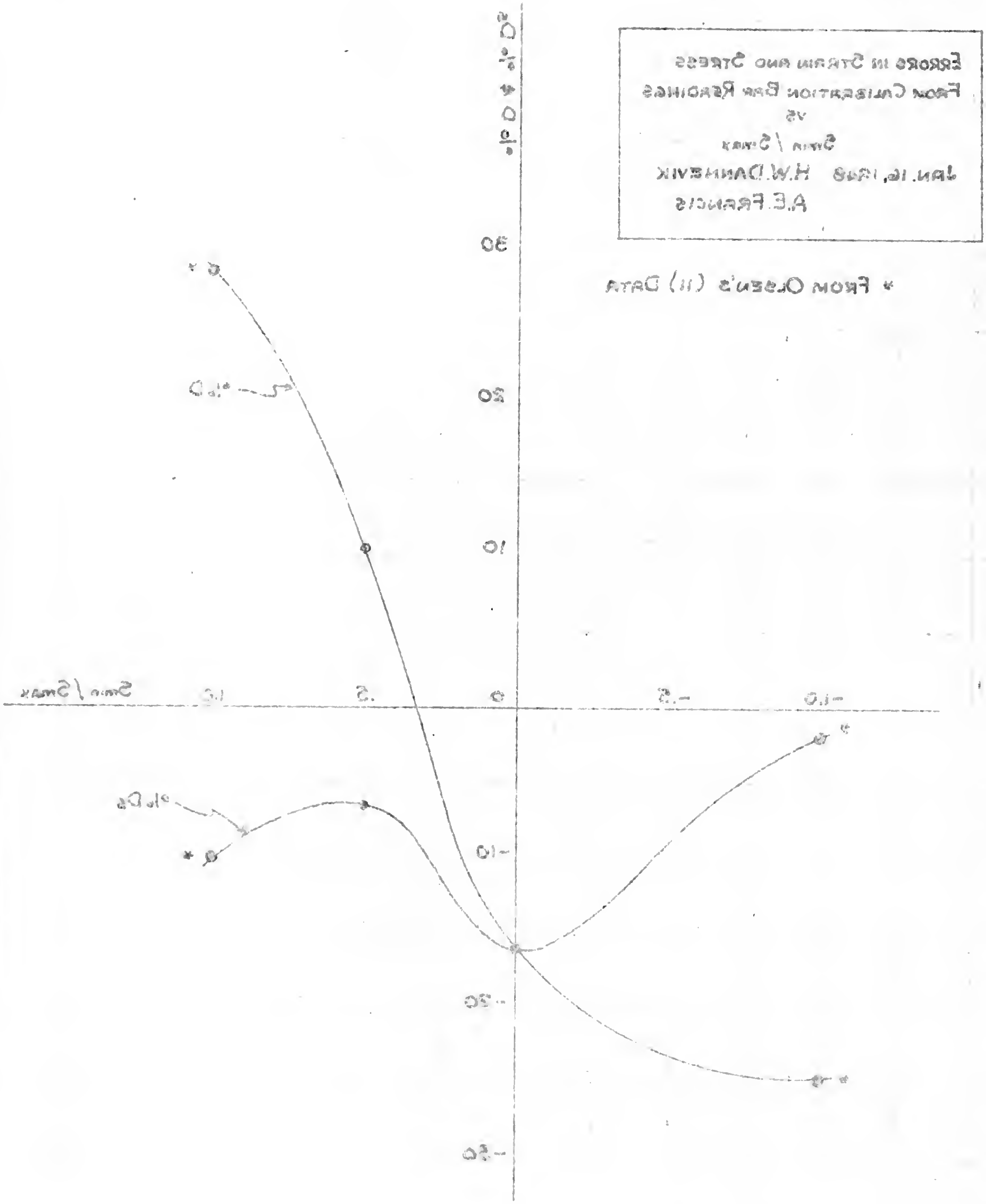
b. Experiments, conducted with a 12 inch square piece of celluloid loaded as a cantilever beam to a certain deflection in one direction and then to the same deflection in the same length of time in a direction perpendicular to the first test, indicated that a crack pattern in one direction had little if any effect on the formation of a crack pattern at right angles to the original pattern. Of four tests made in this manner every one indicated identical sensitivity in either direction.

FIGURE I



ERRORS IN STRAIN AND STRESS
FROM CALIBRATION BAR READINGS
VS
(Emin/Emax)/(e/E)
JANUARY 16, 1948 H.W. DANNEVIK
A.E. FRANCIS
* FROM OLSEN'S (11) DATA
%D & %Ds
%D
%Ds
Emin/Emax
e/E
30
20
10
0
-10
-20
-30
-3.0
-2.0
-1.0
1.0
2.0
3.0

Figure II


Errors in Strain and Stress
From Calibration Bar Readings
vs
Smin / Smax
Jan. 16, 1948 H.W. Dannevik
A.E. Francis
* From Olsen's (11) Data
% D
% Ds
Smin / Smax
30
20
10
-10
-20
-30
1.0
.5
0
-.5
-1.0

DISCUSSION OF RESULTS

General

Conclusions concerning the overall trends of the behavior of Stresscoat are the only ones which can be drawn from the results which have been presented. The lack of facilities for controlling atmospheric conditions rendered it impossible to obtain even two identical runs. The temperature, humidity and grade of Stresscoat used were continuously varying throughout all runs. Therefore, it was impossible to compare the results of runs except for discerning a general picture. Results of specific comparison value can be obtained only by varying a single condition influencing the behavior of Stresscoat while other influencing agents are maintained constant. Desirable results may be obtained either by making all tests in a room where the temperature and humidity are controlled or by running such a large number of tests that the required number of identical runs occur by coincidence. Lack of facilities prevented using the former method and lack of time prevented using the latter.

Although Stresscoat used in the field by an experienced operator may in some cases give accuracy within the limits required by engineering practice, the desirability of spending much time on investigation of its behavior relative to the various elastic theories is questionable unless more adequate facilities for experimentation are made available.

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Although Stresscoat used in the field by an experienced operator may in some cases give accuracy within the limits required by engineering practice, the desirability of spending much time on investigation of its behavior relative to the various elastic theories is questionable unless more adequate facilities for experimentation are made available.

The lack of temperature control also caused difficulty in maintaining equality of temperature between the specimen and the calibration bars, if the room temperature changed during the test. The difference in mass made the bars change in temperature much more quickly than the specimen did. This situation required artificial heating and cooling and often delayed runs annoyingly. The coatings, especially the more sensitive ones, were very susceptible to even small changes in temperature. A drop of two degrees in temperature may change the strain indicated by the lacquer of the order of one hundred micro inches.

No attempt was made to correlate stress with strain for any one run. The length of the specimen tended to reduce any deviation from pure axial loading during the tensile runs, but the slight disagreement between diametrically opposite strain gauges indicated some angularity of loading or local discontinuity of wall thickness. A slight discrepancy in strain gauge readings was also present during pressure runs. This disagreement was probably due to the bending of the specimen in the cradle, as the cracks in the coating appeared first on the bottom of the specimen, where the wall was subjected to tensile bending stress in addition to the stress from internal pressure. These conditions and some variance in the position of the specimen during the successive tests account for the occurrence of different strains in one direction when the strains in the perpendicular

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Two-Dimensional Strain

The results obtained, combined with information determined by Olsen (11), give a rough overall picture of how the magnitude of the deviation of the calibration bar strain from the actual strain varies as the ratio of the two-dimensional strain varies from positive to negative unity. The internal pressure tests of this report E_{min}/E_{max} = .25 and the Olsen (11) hollow sphere test E_{min}/E_{max} = 1.0 indicated that as the ratio of E_{min}/E_{max} increases in a positive direction the amount of strain necessary to cause failure in the coating on the specimen becomes progressively less than that indicated by the calibration bars. Olsen's (11) pure torsion test E_{min}/E_{max} = -1.0 indicates that as the ratio of E_{min}/E_{max} approaches negative unity the strain necessary to cause failure in the coating on the specimen becomes progressively greater than the strain indicated by the calibration bar.

A positive theoretical explanation for the behavior of Strescoat described above was not attained. However, a possible explanation has been developed, but it depends on the following two assumptions for validity:

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A positive theoretical explanation for the behavior of Stresscoat described above was not attained. However, a possible explanation has been developed, but it depends on the following two assumptions for validity.

(1) The stress in the coating is due to the strain in the base material and has no direct connection with the load on the specimen.

(2) Stresscoat fails in tension according to the Maximum Stress Theory.

When E_{min}/E_{max} is positive the Poisson effect of E_{min} tends to shorten the coating in the E_{max} direction. Each point in the coating is restrained by the surrounding lacquer so a tensile stress is induced in the E_{max} direction. Therefore, less direct tension is required to produce failure than if the tension induced due to E_{min} did not exist and the coating fails at a strain lower than that indicated by the calibration bar. When E_{min}/E_{max} is negative the Poisson effect of E_{min} tends to lengthen the coating in the E_{max} direction and a compression stress is induced in the lacquer in the E_{max} direction. For failure to occur in the coat, an amount of tension sufficient to overcome the induced compression is necessary in addition to the normal direct tension required for coat failure if the induced compression were not present. Consequently, the coat fails at a higher value of strain than indicated by the calibration bar. Both Olsen (11) and Durelli (14) experienced difficulty in producing failure in the coating, due to Poisson's effect only, in a direction perpendicular to a compression load. Such behavior of the lacquer conforms to the above theory.

Calibration

According to theory an element on the surface of a

specimen loaded with axial tension only and an element on the top of a loaded cantilever beam are both subjected to the same pattern of two-dimensional strain. In the tension runs the ratio E_{min}/E_{max} was equal to Poisson's ratio as expected; therefore, the disagreement between the actual strain causing failure and the strain indicated by the calibration bar was puzzling. The actual strain required to cause failure of the coating on the specimen was about 15% greater than that indicated by the calibration bar.

A check was made to insure that the calibration bar conformed to beam theory and Poisson's effect, and the results were positive. Further thought has made apparent a possible explanation for the disagreement described above. The thickness of the coat on the calibration bar is an appreciable fraction of the distance from the neutral axis to the outer surface of the bar. Consequently, the strain at the outer surface of the coating is greater than the actual strain on the bar surface underneath. Since the calibration frame is graduated in strain on the bar surface and the cracks initiate on the outer surface of the coat, the strain initiating the cracks is greater than that indicated by the calibration bar. When a specimen is under axial load the strain throughout the coating is the same as that on the surface of the specimen. The assumption that the strain in the outer surface of the bar coating and the strain in the tensile specimen were approximately the same accounts for the discrepancies observed. In contrast to the case of the calibration bar, during tensile runs the cracks were observed specimen loaded with axial tension only and an element on the top of a loaded cantilever beam are both subjected to the same pattern of two-dimensional strain. In the tension runs the ratio $\epsilon_{min}/\epsilon_{max}$ was equal to Poisson's ratio as expected; therefore, the disagreement between the actual strain causing failure and the strain indicated by the calibration bar was puzzling. The actual strain required to cause failure of the coating on the specimen was about 15% greater than that indicated by the calibration bar.

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Olsen's tensile investigation strengthens the theory presented above. The deviations he obtained compare favorably in magnitude and sign with those observed in this experiment. He commented on the inaccuracy of calibration but did not attach any significance to the fact that in each of his runs the calibration bar indicated strains less than those actually present.

The experience of Olsen and the authors suggest that there is an inherent error in strains indicated by the calibration bar except where the specimen is loaded in a condition of bending similar to that in the bar. This error is independent of that due to a particular condition of two-dimensional strain in the specimen.

Curves

In figures 1 and 2 the errors in strain and stress encountered when using the calibration bar are plotted as functions of S_{min}/S_{max} and $\frac{E_{min}/E_{max}}{e/E}$. During the tensile run the two-dimensional strain systems are the same in the specimen and the bar and the only error is the inherent error due to coat thickness which is always present when using the calibration bar. As far as stress is concerned this error, occurring alone for the condition of uniaxial stress, is the maximum error ever present. Evidently the error brought in due to the difference in the two-dimensional to originate on the surface of the base material and then spread outward through the coat.

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Effect of Existing Cracks on Failure in Another Direction

When pressure runs were made after a tensile crack pattern had been previously obtained the calibration bar indicated less strain than that actually required to cause failure on the specimen. This occurrence, which is just opposite to that observed for initial pressure runs, was not satisfactorily understood. The circumferential closely spaced cracks already present eliminate the axial restraint normally present in an intact coating. This condition combined with the possibility of a creep effect (the technique claimed to eliminate creep by the manufacturer was always used) are the only apparent factors which may contribute to the peculiar behavior of the coating.

An attempt to gain further insight into this problem was made by experimenting with the flat celluloid plate. The results, indicating that cracks in one direction do not strain system in the specimen and the bar and the inherent error tend to be compensating and reduce the total error in stress determination. When strain is the important consideration it is noted that the maximum error occurs at the extremities of the possible $\frac{\varepsilon_{min}/\varepsilon_{max}}{\sigma/E}$ range. For strain determinations the point where one error completely compensates for the other error occurs where $\varepsilon_{min}/\varepsilon_{max}$ has a value of about .25. The seriousness of these errors depends on the experimental error probable for the conditions of the test and the accuracy required.

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Crazing

The runs made specifically to investigate the effect of crazing and those pressure and tensile runs where unintentional crazing occurred prior to the run, both indicated that the presence of crazing substantially decreases the sensitivity of the coating as well as making the initial cracks difficult to see. (As the sensitivity of the coating increases it fails at a lower value of strain). The error induced probably varies directly with the intensity of crazing. The more sensitive coats were more susceptible to crazing. The occurrence of crazing depended on the minimum temperature experienced prior to testing and also the rate of fall of the temperature. Even small changes in temperature caused crazing if the change was swift enough. Decreases in temperature caused stresses in the coating due to different thermal coefficients of expansion in the Stresscoat and the material underneath, which are finally relieved by crazing of the coating. After crazing has occurred much of the restraint in the coating at a local point due to the presence of the surrounding coating has been eliminated. When crazing occurred on bars which already contained a crack influence cracking in the other perpendicular direction, did not increase the understanding of the situation. However, cracks on the edges of the crack patterns on the plate were farther apart, shorter and less well developed than the cracks which extended over the whole specimen.

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Accuracy

The effect of creep is pronounced and should not be underestimated. A slight deviation was present between results obtained by loading the calibration bar in the same time as the specimen, and by using the creep correction chart supplied by the manufacturer and loading the bar in one second. However, this deviation was inconsistent in sign and probably was due to normal experimental error.

Most of the published material concerning the use of Stresscoat, except the manufacturer's detailed instructions, underestimate the difficulties which will be encountered in using Stresscoat when atmospheric conditions are not controllable.

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Future Work

It is desirable that the behavior of Stresscoat be investigated for other conditions of biaxial stress in addition to those covered by this report. This additional information would confirm or disprove the shape of the curves of Figures 1 and 2. An attempt to obtain failure of the coat at other ratios of E_{min}/E_{max} was made but the uniform application of internal pressure and axial load simultaneously, which is required due to the creep characteristics of the coating, was impossible with the experimental set-up and the personnel available. The production of apparatus to accomplish this should not be difficult. The use of a small specimen is recommended.

The Poisson's ratio and the modulus of elasticity of Stresscoat itself are important characteristics, the determination of which will allow further insight into the behavior of Stresscoat. With controlled atmospheric conditions it will be possible to limit a series of runs to one grade of Stresscoat. If the Poisson's ratio and the modulus of elasticity for a particular grade of Stresscoat are known, together with the principal strains existing at failure over the possible range of biaxial stress conditions, the actual stress in the coating at failure can be determined. The values of such stresses can be employed to ascertain the theory of failure which Stresscoat follows.

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Summation

The discussions presented have been based on averages of several runs. Although the spread of results for each series of similar runs was quite wide, all the results for each series of runs were of the same sign. After considering the unfavorable conditions under which the investigations were made it is felt that the consistency of the results obtained, and the favorable comparison with Olsen's (11) work, have allowed the authors to present a reasonably accurate overall picture.

CONCLUSIONS

1. If results of theoretical value are to be obtained from experimenting with Stresscoat the experiments must be conducted in a controlled atmosphere.
2. The presence of biaxial stresses in a specimen under investigation and the consequent difference between the two-dimensional strain systems in the specimen and the calibration bar cause the strain indicated by the calibration bar to err from that strain causing failure in the Stresscoat on the specimen. The magnitude and direction of this deviation varies, as the ratio of minimum to maximum strain in the specimen changes from the corresponding ratio in the calibration bar.
3. When the specimen under investigation is loaded in a different manner than the calibration bar the strain indicated by the calibration bar is in error.
4. For stress determinations the two errors above are compensating and the total error is a maximum when the inherent calibration bar error is the only one present.
5. For strain determinations the maximum positive and negative errors occur at the extremities of the $\frac{E_{min}/E_{max}}{e/E}$ and S_{min}/S_{max} ranges. Somewhere within the extremities there is a point of no error.
6. Crazing affects the sensitivity of Stresscoat. The presence of previously obtained crack pattern affects the sensitivity of the coating to cracking in another direction.

RECOMMENDATIONS

1. If further investigation in the field of strain indicating brittle lacquer is undertaken, facilities for experimenting under controlled atmospheric conditions should be supplied.
2. Further investigation of the behavior of Stresscoat when subjected to biaxial stress should be made under controlled atmospheric conditions and for more ratios of S_{min}/S_{max}.
3. The Poisson's ratio and modulus of elasticity and then the theory of failure of Stresscoat should be determined.
4. An investigation of the causes and affects of crazing on the behavior of Stresscoat should be made.

APPENDIX

APPENDIX A

DETAILS OF PROCEDURE

Description of Apparatus

Specimen

The body of the specimen was a drawn seamless tube. The outside diameter was $4\frac{1}{2}$ inches and the wall thickness was .140 inches. The material conformed with Navy Specification N-44-T-13, Cat. No. 1077, 44-T-5450-10. The composition was .25% carbon, .70% Manganese, .04% Phosphorous, and .04% Sulphur. The yield point was 35,000 psi and the ultimate strength was 60,000 psi. The length of the body was 30 inches.

The ends were machined from rough steel forgings. The inner extremities of the ends were machined to fit snugly into the tube for a distance of two inches. The outer extremities were turned down to two inches in diameter and then drilled and tapped with a $1\frac{1}{4}$ inch, 7 threads per inch tap. The end pieces were secured to the body by both fillet and plug welds.

Each end of the specimen was fitted with a 6,000 psi valve. One end was connected to the pump through a portable section of high pressure copper tubing by means of two heavy duty unions.

Strain Gauges and Strain Indicator

The SR-4 strain gauges were bonded resistance wire type strain gauges manufactured by the Baldwin Southwark

Division, Baldwin Locomotive Works. The specific type gauge used was an A-3, 13/16 inch gauge length, 120 ohm, and with a gauge factor of 2.03. The strain readings were obtained by the use of an SR-4 Strain Gauge Indicator, also manufactured by Baldwin.

Testing Machine

The tensile loading machine that was used was a Riehle Tensile Testing Machine, No. 214, having a maximum load capacity of 100,000 lbs. It was located in the Material Test Laboratory, Massachusetts Institute of Technology.

Hydraulic Pump

The pump used was a 10,000 lb. capacity hydraulic pump, a type sometimes used as a jack.

Division, Baldwin Locomotive Works. The specific type gauge used was an A-5, 13/16 inch gauge length, 120 ohm, and with a gauge factor of 2.05. The strain readings were obtained by the use of an SR-4 strain gauge indicator, also manufactured by Baldwin.

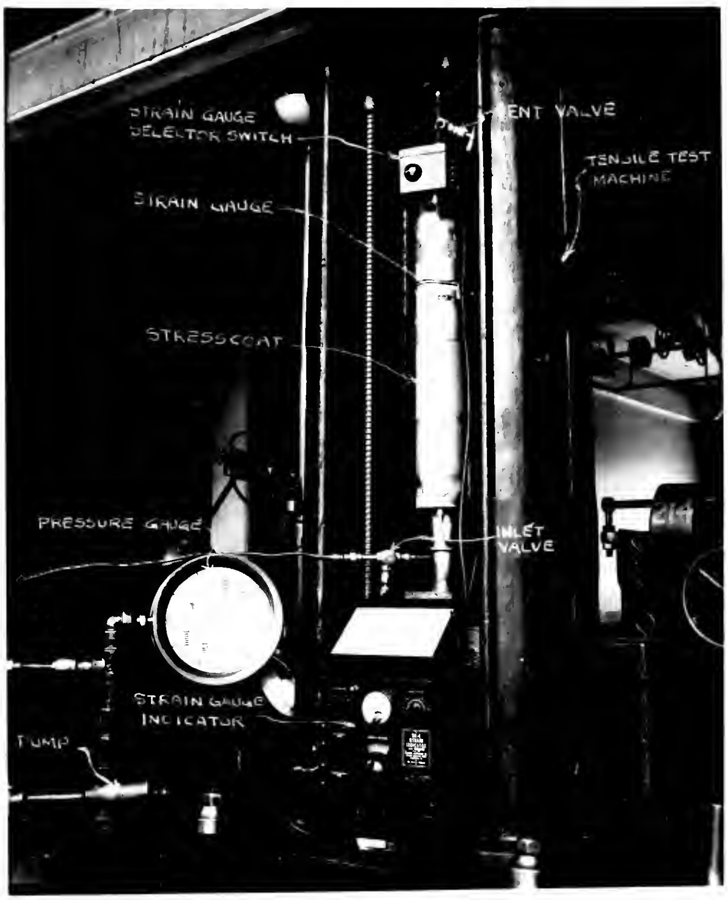
Testing Machine

The tensile loading machine that was used was a Riehle Tensile Testing Machine, No. 214, having a maximum load capacity of 100,000 lbs. It was located in the Material Test Laboratory, Massachusetts Institute of Technology.

Hydraulic Pump

The pump used was a 10,000 lb. capacity hydraulic pump, a type sometimes used as a jack.

Experimental Specimen



Experimental Arrangement

APPENDIX B

SAMPLE CALCULATIONS

Correction for Lateral Sensitivity of SR-4 Strain Guage

The corrections for lateral sensitivity were made as outlined in reference (15). SR-4 strain guages are calibrated for uniaxial stress along the axis, on steel having a Poisson's ratio, V, of .285. In any case involving two guages at right angles, if the conditions of strain under which the guages were calibrated are given, it is possible to find the true strains by the two simultaneous equations:

$$E_{max} = \frac{(1 - V_o K)(e_{max} - K e_{min})}{(1 - K^2)}$$

$$E_{min} = \frac{(1 - V_o K)(e_{min} - K e_{max})}{(1 - K^2)}$$

Where symbols have meanings shown by Table of Symbols.

Typical Pressure Run (No. 17) t = 225 seconds.

$$e_a = (230 + 220)/2 = 225 \qquad e_c = (850 + 840)/2 = 845$$

$$E_a = \frac{[1 - (.285)(.021)][225 - (.021)(845)]}{[1 - (.021)^2]} = 206 = E_{min}$$

$$E_c = \frac{[1 - (.285)(.021)][845 - (.021)(225)]}{[1 - .021^2]} = 835 = E_{max}$$

$$E_a/E_c = E_{min}/E_{max} = 206/835 = .247$$

APPENDIX B

SAMPLE CALCULATIONS

Correction for Lateral Sensitivity of SR-4 Strain Gauge

The corrections for lateral sensitivity were made as outlined in reference (15). SR-4 strain guages are calibrated for uniaxial stress along the axis, on steel having a Poisson's ratio, V, of .285. In any case involving two guages at right angles, if the conditions of strain under which the guages were calibrated are given, it is possible to find the true strains by the two simultaneous equations:

$$E_{max} = \frac{(1 - V_0 K)(e_{max} - K e_{min})}{(1 - K^2)}$$

$$E_{min} = \frac{(1 - V_0 K)(e_{min} - K e_{max})}{(1 - K^2)}$$

Where symbols have meanings shown by Table of Symbols.

Typical Pressure Run (No. 17) t = 225 seconds.

$$e_a = (230 + 220)/2 = 225 \qquad e_c = (850 + 840)/2 = 845$$

$$E_a = \frac{[1 - (.285)(.031)][225 - (.031)(845)]}{[1 - (.031)^2]} = 206 = E_{min}$$

$$E_c = \frac{[1 - (.285)(.031)][845 - (.031)(225)]}{[1 - .031^2]} = 835 = E_{max}$$

$$E_a/E_c = E_{min}/E_{max} = 206/835 = .247$$

APPENDIX B

SAMPLE CALCULATIONS

For Calibration bar loaded in 225 seconds.

$$E = (920 + 920 + 860)/3 = 900$$

$$E - E_c = 900 - 835 = 65$$

$$\% D = (100)(65)/(835) = 7.7\%$$

For calibration bar loaded in 1 second and creep corrected.

$$E = (1000 + 960 + 1000)/3 = 987$$

Typical Tensile Run (No. 23) t= 70 seconds

$$e_a = (655 + 620)/2 = 638 \qquad e_c = (-210 - 180)/2 = -195$$

$$E_a = \frac{[1 - (.285)(.021)][638 - (.021)(-195)]}{[1 - (.021)^2]} = 637 = E_{max}$$

$$E_c = \frac{[1 - (.285)(.021)][-195 - (.021)(638)]}{[1 - (.021)^2]} = -207 = E_{min}$$

$$E_c/E_a = E_{min}/E_{max} = -207/637 = -.325$$

For calibration bar loaded in 70 seconds.

$$E = 450 \qquad E - E_a = 450 - 637 = -187$$

$$\% D = (100)(-187)/(637) = -29.4\%$$

APPENDIX B

SAMPLE CALCULATIONS

For calibration bar loaded in 275 seconds.

$$E = (920 + 920 + 860)/3 = 900$$

$$E - E_c = 900 - 835 = 65$$

$$\% D = (100)(65)/(835) = 7.7\%$$

For calibration bar loaded in 1 second and creep corrected.

$$E = (1000 + 960 + 1000)/3 = 987$$

Typical results [illegible] 1.5 [illegible] seconds

$$e_a = (655 + 620)/2 = 638 \qquad e_c = (-210 - 180)/2 = -195$$

$$E_a = \frac{[1 - (.285)(.021)][638 - (.021)(-195)]}{[1 - (.021)^2]} = 637 = E_{max}$$

$$E_c = \frac{[1 - (.285)(.021)][-195 - (.021)(638)]}{[1 - (.021)^2]} = -207 = E_{min}$$

$$E_c/E_a = E_{min}/E_{max} = -207/637 = -.325$$

For calibration bar loaded in 70 seconds.

$$E = 450 \qquad E - E_a = 450 - 637 = -187$$

$$\% D = (100)(-187)/(637) = -29.4\%$$

APPENDIX B

SAMPLE CALCULATIONS

For calibration bar loaded in 1 second and creep corrected.

$$E = (580 + 430 + 560)/3 = 523$$

Stress Calculations

For the calibration bar case.

$$S_{max} = \frac{E_M(\mathcal{E} + \nu e)}{(1-\nu^2)} \qquad e = -.295\mathcal{E} = -\nu\mathcal{E}$$

$$S_{max} = \frac{E_M(\mathcal{E} - \nu^2\mathcal{E})}{1-\nu^2} = \frac{E_M(1-\nu^2)\mathcal{E}}{1-\nu^2} = E_M\mathcal{E}$$

For the cylinder under internal pressure.

$$\mathcal{E}_{min} = .25\mathcal{E}_{max} \qquad \mathcal{E}_{max} = .905\,\mathcal{E}$$

$$S_{max} = \frac{E_M(\mathcal{E}_{max} + \nu\mathcal{E}_{min})}{(1-\nu^2)} = \frac{E_M\left[\mathcal{E}_{max} + (.295)(.25)\mathcal{E}_{max}\right]}{.913}$$

$$= \frac{(1.0738)(E_M\mathcal{E}_{max})}{.913} = \frac{(1.0738)(.905)E_M\mathcal{E}}{.913} = 1.064\,E_M\mathcal{E}$$

$$\%\,D_s = (100)(1-1.064)/(1.064) = -6.1\%$$

The calculations for the cases of pure torsion, axial load, and the sphere under internal pressure are similar to those above.

For calibration bar loaded in 1 second and creep corrected.

$$E = (580 + 430 + 560)/3 = 523$$

Stress Calculations

For the calibration bar same.

$$S_{max} = \frac{E_M(E + \nu e)}{(1-\nu^2)} \qquad e = -.295E = -\nu E$$

$$S_{max} = \frac{E_M(E - \nu^2 E)}{1-\nu^2} = \frac{E_M(1-\nu^2)E}{1-\nu^2} = E_M E$$

For the cylinder under internal pressure.

$$E_{min} = .25E_{max} \qquad E_{max} = .905\,E$$

$$S_{max} = \frac{E_M(E_{max} + \nu E_{min})}{(1-\nu^2)} = \frac{E_M\left[E_{max} + (.295)(.25)E_{max}\right]}{.913}$$

$$= \frac{(1.0738)(E_M E_{max})}{.913} = \frac{(1.0738)(.905)E_M E}{.913} = 1.064\,E_M E$$

$$\%\,D_s = (100)(1-1.064)/(1.064) = -6.1\%$$

The calculations for the cases of open cylinders, half-load, and the cases under internal pressure are similar to those above.

APPENDIX C

ORIGINAL DATA

Test #17	Application	Test
Date	5 Dec 1947	6 Dec 1947
Time	1300	1000
Wet Bulb	50.5° F	50° F
Dry Bulb	71° F	66° F
#Stresscoat Used	#1204	#1204
#Stresscoat Called For	#1202	#1201
Time of Loading Specimen		225 sec

Specimen Temp. at time of coat failure: 70.5° F

Internal Pressure psi gage	Axial Load Lbs.	Strain Gage (micro inches)			
		1	2	3	4
0	0	420	250	850	180
		#8 ref	#4	#5	#7
2100	0	650	1100	1070	1020
		#8	#4	#5	#7
0	0	455	250	840	175
		#8	#4	#5	#7

Calibration Bar No.	1	2	3	4	5	6
Strain, Micro Inches	780	750	920	920	780	860
Time of Loading Bar, Secs.	1	1	225	225	1	225
Bar Temperature, degrees F	70.5	70.5	70.5	70.5	70.5	70.5

Test #17	Calibration	Test
Date	3 Dec 1947	3 Dec 1947
Time	1300	1000
Wet Bulb	56.5° F	50° F
Dry Bulb	71° F	66° F
%Stresscoat Used	1204	1204
%Stresscoat Called For	1202	1201
Time of Loading Specimen		225 sec

Specimen Temp. at time of coat failure: 70.5° F

Internal Pressure psi gage	Axial Load Lbs.	Strain Gage (micro inches) 1	2	3	4
0	0	420	250	650	180
		#6 ref	#4	#5	#7
2100	0	650	1100	1070	1020
		#8	#4	#5	#7
0	0	455	250	640	175
		#6	#4	#5	#7

Calibration Bar No.	1	2	3	4	5	6
Strain, micro inches	790	750	920	920	780	850
Time of loading bar, secs.	1	1	225	225	1	225
Bar temperature, degrees F	70.5	70.5	70.5	70.5	70.5	70.5

Test #18	Application	Test
Date	6 Dec 1947	7 Dec 1947
Time	1100	1000
Wet Bulb	50° F	52° F
Dry Bulb	66° F	70.5° F
#Stresscoat Used	#1204	#1204
#Stresscoat Called For	#1201	
Time of Loading Specimen		120 sec

Specimen Temp. at time of coat failure: 69° F

Internal Pressure psi gage	Axial Load Lbs.	Strain Gage (micro inches) 1	2	3	4
0	0	505	415	1185	340
		#8 ref	#4	#5	#7
1925	0	750	1210	1370	1120
		#8	#4	#5	#7

Calibration Bar No.	1	2	3	4	5	6
Strain, Micro Inches	680	950	700	905	1010	800
Time of Loading Bar, Secs.	1	120	1	120	120	1
Bar Temperature, degrees F	69	69	69	69	69	69

Remarks:

It was necessary to cool bars and specimen to obtain sensitivity of practical value. A marked variation of sensitivity with a small temperature change in bars was noted. One bar spontaneously crazed at 64° F. This bar when bent gave an obviously inconsistent strain reading of 1200 micro inches/inch.

Test #18	Specification	Test
Date	6 Dec 1947	7 Dec 1947
Time	1100	1000
Wet Bulb	50° F	52° F
Dry Bulb	56° F	70.5° F
#Stresscoat Used	#1204	#1204
#Stresscoat Called for	#1201	
Time of Loading Specimen		120 sec

Specimen Temp. at time of coat failure: 69° F

Internal Pressure psi gage	Axial Load Lbs.	Strain Gage (micro inches) 1	2	3	4
0	0	505	415	1135	340
		.18 ref	.4	.75	.47
1925	0	750	1210	1370	1120
		.18	.4	.75	.47

Calibration Bar No.	1	2	3	4	5	6
Strain, Micro Inches	580	950	700	905	1010	800
Time of Loading Bar, secs.	1	120	1	120	120	1
Bar Temperature, degrees F	69	69	69	69	69	69

Remarks:

It was necessary to cool bars and specimen to obtain sensitivity of practical value. A marked variation of sensitivity with a small temperature change in bars was noted. One bar spontaneously cracked at 64° F. This bar when bent gave an obviously inconsistent strain reading of 1200 micro inches/inch.

Test #19	Application	Test
Date	8 Dec 1947	9 Dec 1947
Time	1300	900
Wet Bulb	54° F	54° F
Dry Bulb	74° F	73.5° F
#Stresscoat Used	#1206	#1206
#Stresscoat Called For	#1204	
Time of Loading Specimen		40 sec.

Specimen Temp. at time of coat failure: 73.5° F

Internal Pressure psi gage	Axial Load Lbs.	Strain Gage (micro inches) 1	2	3	4
0	0	390	310	920	280
		#8 ref	#4	#5	#7
1200	0	530	785	-	700
		#8	#4	-	#7

Calibration Bar No.	1	2	3	4	5	6
Strain, Micro Inches	550	450	440	490	490	440
Time of Loading Bar, Secs.	1	1	1	40	40	1
Bar Temperature, degrees F	74.5	73.75	73.5	73.75	73.75	73.5

Test #19	Application	Test
Date	8 Dec 1947	9 Dec 1947
Time	1300	900
Wet Bulb	54° F	54° F
Dry Bulb	74° F	73.5° F
#Stresscoat Used	1206	#1206
#Stresscoat Called For	1204	
Time of Loading Specimen		40 sec.

Specimen Temp. at time of coat failure: 73.5° F

Internal Pressure psi gage	Axial Load Lbs.	Strain Gage (Micro Inches) 1	2	3	4
0	0	590	310	920	280
		6 ref	4	5	7
1200	0	550	725	-	700
		6	4	-	7

Calibration Bar No.	1	2	3	4	5	6
Strain, Micro Inches	550	450	440	490	490	440
Time of Loading Bar, sec.	1	1	1	40	40	1
Bar Temperature, degrees F	74.5	73.75	73.5	73.75	73.75	73.5

Test #20	Application	Test
Date	9 Dec 1947	10 Dec 1947
Time	1300	1300
Wet Bulb	54° F	53° F
Dry Bulb	74° F	71.5° F
#Stresscoat Used	#1205	#1205
#Stresscoat Called For	#1203	
Time of Loading Specimen		50 sec.

Specimen temp. at time of coat failure: 71.5° F

Internal Pressure psi gage	Axial Load Lbs.	Strain Gage (micro inches) 1	2	3	4
0	0	250	1190	620	1100
		#8 ref	#2	#5	#6
2050*	0	475	1060	840	1940
		#8	#4	#5	#6

Calibration Bar No.	1	2	3	4	5	6	7	8	9	10
Strain, Micro Inches	700	700	860	900	670	780	730	810	790	905
Time of Loading Bar, Secs.	1	1	1	50	1	50	1	50	1	50
Bar Temperature degrees F	71.5	71.5	71.5**	71.5	71.5**	71.5	71.5	71.5	71.5	71.5

Remarks:

* This run was made after the specimen had been loaded in tension to the design strength of the specimen, but no circumferential cracks in Stresscoat were noted. The Stresscoat was allowed to recover for a time in excess of two times the time to load the specimen; before the internal pressure was applied.

** Bar number 3 was a thicker coat than the best specimen and Bar number 5 was an exceedingly thin coat.

Test #20	Application	Test
Date	9 Dec 1947	10 Dec 1947
Time	1300	1200
Wet Bulb	54° F	55° F
Dry Bulb	74° F	71.5° F
#Stresscoat Used	1205	1205
#Stresscoat Called for	1205	
Time of Loading Specimen		50 sec.

Specimen temp. at time of coat failure: 71.5° F

Internal Pressure psi gage	Axial Load Lbs.	Strain Gage (Micro Inches) 1	2	3	4
0	0	550	1150	580	1100
		[illegible] 1	2	5	6
2050*	0	475	1050	940	1940
		13	4	15	16

Calibration Bar No.	1	2	3	4	5	6	7	8	9	10
Strain, Micro Inches	700	700	850	900	670	780	730	810	790	905
Time of Loading Bar, Secs.	1	1	1	50	1	30	1	50	1	50
Bar Temperature degrees F	71.5	71.5	71.5	71.5**	71.5	71.5**	71.5	71.5	71.5	71.5

Remarks:

* This run was made after the specimen had been loaded in tension to the design strength of the specimen, but no circumferential cracks in stresscoat were noted. The Stresscoat was allowed to recover for a time in excess of two times the time to load the specimen before the internal pressure was applied.

** Bar number 3 was a failure [illegible] to bent specimen and bar number 5 had an exceedingly thin coat.

Test #21	Application	Test
Date	10 Dec 1947	11 Dec 1947
Time	1600	1300
Wet Bulb	53° F	52° F
Dry Bulb	71.5° F	70.75° F
#Stresscoat Used	#1205	#1205
#Stresscoat Called For	#1202	
Time of Loading Specimen		60 sec

Temp. of specimen at time of coat failure: 70.75° F

Internal Pressure psi gage	Axial Load Lbs.	Strain Gage (micro inches) 1	2	3	4
0	0	240	180	590	80
		#8 ref	#4	#5	#7
2175*	0	440	1090	830	980
		#8	#4	#5	#7

Calibration Bar No.	1	2	3-A	3-B	4-A	4-B	5
Strain, Micro Inches	900	900	960	810	1010	800	800
Time of Loading Bar, Secs.	1	1	60	1	60	1	1
Bar Temperature, degrees F	70.75	70.75	71.5	71.5	71.5	71.5	71.5

Remarks:

* This run was made after the specimen had been loaded in tension to the design strength of specimen but no cracks were noted in the Stresscoat. The Stresscoat was allowed to recover for a time in excess of two times the time allowed to load the specimen, before the internal pressure was applied.

Test #22	Application	Test
Date	11 Dec 1947	12 Dec 1947
Time	1600	1300
Wet Bulb	52° F	53° F
Dry Bulb	70.5° F	71° F
#Stresscoat Used	#1206	#1206
#Stresscoat Called For	#1202	
Time of Loading Specimen		(A) 45 sec (B) 75 sec

Temp of Specimen at time of coat failure: 71.5° F

Internal Pressure psi gage	Axial Load Lbs.	Strain Gage (micro inches) 1	2	3	4
0	0	260	230	640	130
		#8 ref	#4	#5	#7
(A)* 1900	0	480	980	830	870
		#8	#4	#5	#7
(B) 1470	35000	935	660	1270	570
		#8	#4	#5	#7

Calibration Bar No.	3A	3B
Strain, Micro Inches	730	730
Time of Loading Bar, Secs.	1	75
Bar Temperature, degrees F	71.5	71.5

Remarks:

Longitudinal cracks (very apparent) appeared with P_i = 1900 psig. and P_a = 0 in test A Time of loading 45 sec. Circumferential cracks appeared with loading P_i = 1470 psig. and P_a = 35000 lbs. as indicated. Time of loading 75 secs.

Both the bars and the specimen were badly crazed, however, the cracks from loading were readily apparent on the specimen, but were almost impossible to see on the bars.

* This run was made after the specimen had been loaded in tension with no cracks appearing in Stresscoat. It was allowed to recover.

Test #22

	Application	Test
Date	11 Dec 1947	12 Dec 1947
Time	1600	1300
Wet Bulb	52° F	53° F
Dry Bulb	70.5° F	71° F
#Stresscoat Used	#1206	#1206
#Stresscoat Called for	#1206	
Time of Loading Specimen		(A) 45 sec (B) 75 sec

Temp of Specimen at time of coat failure: 71.5° F

Internal Pressure psi gage	Axial Load Lbs.	Strain Gage (micro inches) 1	2	3	4
0	0	260	230	540	150
		.8% rel	.4	.5	.7
(A)* 1900	0	480	990	830	870
		.8	.4	.5	.7
(B) 1470	35000	935	660	1270	570
		.8	.4	.5	.7

Calibration Bar No.	54	58
Strain, Micro Inches	730	730
Time of Loading Bar, Secs.	[illegible]	75
Bar Temperature, degrees F	71.5	71.5

Remarks:

Longitudinal cracks (very apparent) appeared with P_i = 1900 psig, and P_a = 0 in test A. Time of loading 45 sec. Circumferential cracks appeared with loading P_i = 1470 psig. and P_a = 35000 lbs. as indicated. Time of loading 75 secs. Both the bars and the specimen were badly crazed, however, the cracks from loading were readily apparent on the specimen, but were almost impossible to see on the bars.

* This run was made after the specimen had been loaded in tension with no cracks appearing in Stresscoat. [illegible] was allowed to recover.

Test #23	Application	Test
Date	12 Dec 1947	13 Dec 1947
Time	1500	1000
Wet Bulb	53° F	54° F
Dry Bulb	71° F	70° F
#Stresscoat Used	#1207	#1207
#Stresscoat Called For	#1202	

Time of Loading Specimen (A) 70 sec (B) 25 sec

Temp of Specimen at time of coat failure: 70.5°F (A) & (B)

Internal Pressure psi gage	Axial Load Lbs.	Strain Gage (micro inches) 1	2	3	4
0	0	315/#8 ref	1260/#3	680/#5	1150/#6
(A) 0	36,580	970/#8	1050/#3	1300/#5	970/#6
0	0	320/#8	270/#4	680/#5	140/#7
(B) 1475	0	465/#8	860/#4	830/#5	745/#7

Calibration Bar No.	1A	1B	2A	3A	4A	4B	5	6
Strain, Micro inches	870	580	450	450	700	560	520	500
Time of Loading Bar, Secs.	1	1	70	1	70	1	25	25
Bar Temperature, degrees F	74.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5

Remarks:

Specimen and bars were heated to approximately 80°F during the drying period and then allowed to assume room temperature prior to the test.

Test (B) was made after the crack pattern of part (A) had been obtained. Sufficient time for creep recovery of the coat was allowed between tests.

Test 123

	Application	Test
Date	12 Dec 1947	13 Dec 1947
Time	1500	1000
Wet Bulb	53° F	54° F
Dry Bulb	71° F	70° F
Stresscoat Used	1207	#1207
Stresscoat Called For	#1202	

Time of Loading Specimen (A) 70 sec (B) 25 sec

Temp of Specimen at time of coat failure: 70.5° F (A) & (B)

Internal Pressure psi gage	Axial Load lbs.	Strain Gage (micro inches) 1	2	3	4
0	0	315/+8 for	1260/+3	680/+15	1150/+6
(A) 0	36,380	970/+8	1050/+3	1300/+5	970/+6
0	0	520/+8	270/+4	560/+5	140/+7
(B) 1475	0	465/+8	355/+4	830/+5	745/+7

Calibration Bar No.	1A	1B	2A	3A	4A	4B	5	6
Strain, Micro Inches	270	480	450	450	700	550	520	500
Time of Loading Bar, Secs.	1	1	70	1	70	1	25	25
Bar Temperature, degrees F	71.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5

Remarks:

Specimen and bars were heated to approximately 80°F during the drying period and then allowed to assume room temperature prior to the test.

Test (B) was made after the crack pattern of part (A) had been obtained. Sufficient time for creep recovery of the coat was allowed between tests.

Test #24	Application	Test
Date	15 Dec 1947	16 Dec 1947
Time	1200	1000
Wet Bulb	54°F	58°F
Dry Bulb	73°F	76°F
#Stresscoat Used	#1208	#1208
#Stresscoat Called For	#1203	

Time of Loading Specimen (A) 65 sec (B) 25 sec

Temp. of specimen at time coat failed: 76°F

Internal Pressure psi gage	Axial Load Lbs.	Strain Gage (micro inches) 1	2	3	4
0	0	375/#8	1330/#3	725/#5	1200/#6
(A) 0	36,000	1045/#8	1155/#3	1360/#5	1050/#6
0	0	380/#8	360/#4	740/#5	230/#7
(B) 1625	0	540/#8	970/#4	885/#5	845/#7
0	0	425/#8	350/#4	720/#5	195/#7

Calibration Bar No.	1	2A	2B	3	4	5	6A*	6B*
Strain, Micro Inches	490	590	530	600	540	590	690	520
Time of Loading Bar, Secs.	1	65	1	65	1	25	25	1
Bar Temperature, degrees F	76	76	76	76	76	76	76	76

Remarks:

Bar #6 was crazed.

Test (B) was made after the crack pattern of Part (A) had been obtained. Sufficient time for creep recovery of the coat was allowed between tests.

Test #24	Application	Test
Date	15 Dec 1947	16 Dec 1947
Time	1200	1000
Wet Bulb	54°F	58°F
Dry Bulb	75°F	76°F
Stresscoat Used	#1208	#1208
Stresscoat Called For	#1203	

Time of Loading Specimen (A) 55 sec (B) 25 sec

Temp. of specimen at time coat failed: 76°F

Internal Pressure psi gage	Axial Load Lbs.	Strain Gage (Micro Inches) 1	2	3	4
0	0	375/#8	1350/#3	725/#5	1200/#6
(A) 0	36,000	1045/#8	1155/#3	1360/#5	1050/#6
0	0	300/#8	360/#4	740/#5	250/#7
(B) 1625	0	540/#8	970/#4	885/#5	845/#7
0	0	425/#8	350/#4	730/#5	195/#7

Calibration Bar No.	1	2A	2B	3	4	5	6A*	6B*
Strain, Micro Inches	490	590	550	600	540	730	690	520
Time of Loading Bar, Secs.	1	55	1	55	1	25	25	1
Bar Temperature, degrees F	76	76	76	76	76	76	76	76

Remarks:

Bar #6 was greased.

Test (B) was made after the crack pattern of Part (A) had been obtained. Sufficient time for creep recovery of the coat was allowed between tests.

Test #25	Application	Test
Date	16 Dec 1947	17 Dec 1947
Time	1300	1400
Wet Bulb	58°F	56½°F
Dry Bulb	76°F	75°F
#Stresscoat Used	#1208	#1208

Time of Loading Specimen (A) 35 sec (B) 28 sec

Temp. of Specimen at time of coat failure: 76.5°F

Internal Pressure psi gage	Axial Load Lbs.	Strain Gage (micro inches) 1	2	3	4
0	0	385/#8	1270/#3	705/#5	1175/#6
(A) 0	34,000	940/#8	1095/#3	1285/#5	1010/#6
0	0	320/#8	290/#4	695/#5	180/#7
(B) 1330	0	470/#8	810/#4	850/#5	695/#7

Calibration Bar No.	1	2A	3	4	5A	5B	6A	6B
Strain, Micro Inches	530	580	500	540	530	620	540	540
Time of Loading Bar, Secs.	1	35	1	35	1	28	1	28
Bar Temperature, degrees F	76.5	76.5	75	75	75	75	75	75

Remarks:

All of the bars were slightly crazed both from drying and from low temperature. It so happened that the craze markings were indiscriminate in direction so that strain cracks could be readily seen. There was no craze on the specimen.

Test (B) was made after the crack pattern of Part (A) had been obtained. Sufficient time for creep recovery of the coat was allowed between tests.

Test #25	Application	Test
Date	16 Dec 1947	17 Dec 1947
Time	1300	1400
Wet Bulb	58°F	56½°F
Dry Bulb	76°F	75°F
%Stresscoat Used	1208	1208

Time of Loading Specimens (A) 35 sec (B) 28 sec

Temp. of Specimen at time of coat failure: 76.5°F

Internal Pressure psi gage	Axial Load Lbs.	Strain Gage (micro inches) 1	2	3	4
0	0	385/#8	1270/#3	705/#5	1175/#6
(A) 0	34,000	940/#8	1095/#3	1285/#5	1010/#6
0	0	320/#8	290/#4	695/#5	180/#7
(B) 1330	0	470/#8	810/#4	850/#5	695/#7

Calibration Bar No.	1	2A	3	4	5A	5B	6A	6B
Strain, Micro Inches	530	580	500	540	530	620	540	540
Time of Loading Bar, Secs.	1	35	1	35	1	28	1	28
Bar Temperature, degrees F	76.5	76.5	75	75	75	75	75	75

Remarks:

All of the bars were slightly crazed with from drying and from low temperature. It so happened that the craze markings were indiscriminate in direction so that strain cracks could be readily seen. There was no craze on the specimen.

Test (B) was made after the crack pattern of Part (A) had been obtained. Sufficient time for creep recovery of the coat was allowed between tests.

Test #26	Application	Test
Date	17 Dec 1947	18 Dec 1947
Time	1600	1300
Wet Bulb	56.5°F	58°F
Dry Bulb	75°F	74°F
#Stresscoat Used	#1208	#1208

Time of Loading Specimen (A) 50 sec (B) 35 sec

Temp. of Specimen at time of coat failure: 75.5°F

Internal Pressure psi gage	Axial Load Lbs.	Strain Gage (micro inches) 1	2	3	4
0	0	370/#8	1315/#3	730/#5	1210/#6
(A) 0	37,000	1050/#8	1130/#3	1400/#5	1050/#6
0	0	400/#8	370/#4	770/#5	250/#7
(B) 1600	0	620/#8	1010/#4	940/#5	890/#7

Calibration Bar No.	1	2	3	4	5	6
Strain, Micro Inches	580	600	600	585	600	640
Time of Loading Bar, Secs.	1	50	50	35	35	35
Bar Temperature, degrees F	76.5	75.5	75.5	75.5	75.5	75.5

Remarks:

Bars badly crazed - Specimen had very little craze.

Test (B) was made after the crack pattern of part (A) had been obtained. Sufficient time for creep recovery of the coat was allowed between tests.

Test 126	Application	Test
Date	17 Dec 1947	18 Dec 1947
Time	1600	1300
Wet Bulb	56.5°F	58°F
Dry Bulb	75°F	74°F
Stresscoat Used	1208	1208

Time of Loading Specimen (A) 50 sec (B) 35 sec

Temp. of specimen at time of coat failure: 75.5°F

Internal Pressure psi gage	Axial Load Lbs.	Strain Gage (micro inches) 1	2	3	4
0	0	370/#2	1315/#3	730/#5	1210/#6
(A) 0	37,000	1050/#8	1150/#3	1400/#5	1050/#6
0	0	400/#8	370/#4	770/#5	250/#7
(B) 1600	0	620/#8	1010/#4	940/#5	890/#7

Calibration Bar No.	1	2	3	4	5	6
Strain, Micro Inches	580	600	600	585	600	640
Time of Loading Bar, secs.	1	50	50	35	35	35
Bar Temperature, degrees F	76.0	75.5	75.5	75.5	75.5	75.5

Remarks:

Bars badly crazed - Specimen had very little craze.

Test (B) was made after the craze pattern of part (A) had been obtained. Sufficient time [illegible] recovery of the coat was allowed between tests.

Test #27	Application	Test
Date	18 Dec 1947	19 Dec 1947
Time	1300	1500
Wet Bulb	58°F	57°F
Dry Bulb	74°F	74°F
#Stresscoat Used	#1207	#1207

Time of Loading Specimen (A) 55 sec (B) 35 sec

Temp. of Specimen at time of coat failure: 74°F

Internal Pressure psi gage	Axial Load Lbs.	Strain Gage (micro inches) 1	2	3	4
0	0	365/#8	1320/#3	735/#5	1200/#6
(A) 0	35,200	1045/#8	1150/#3	1340/#5	1030/#6
0	0	380/#8	345/#4	745/#5	225/#7
(A) 1600	0	570/#8	1000/#4	925/#5	860/#7

Calibration Bar No.	1	2	3	4	5A	6A	5B	6B
Strain, Micro Inches	570	580	580	570	550	540	550	490
Time of Loading Bar, Secs.	1	55	55	55	35	35	1	1
Bar Temperature, degrees F	74	74	74	74	74	74	74	74

Test #27	Application	Test
Date	18 Dec 1947	19 Dec 1947
Time	1300	1300
Wet Bulb	58°F	57°F
Dry Bulb	74°F	74°F
%Stresscoat Used	#1207	#1207
Time of Loading Specimen	(A) 35 sec	(B) 35 sec

Temp. of Specimen at time of coat failure: 74°F

Internal Pressure psi gage	Axial Load Lbs.	Strain Gage (micro inches) 1	2	3	4
0	0	365/#8	1320/#3	735/#5	1200/#6
(A) 0	35,200	1045/#8	1150/#3	1340/#5	1030/#6
0	0	380/#8	345/#4	745/#5	225/#7
(A) 1600	0	570/#8	1000/#4	925/#5	860/#7

Calibration Bar No.	1	2	3	4	5A	6A	5B	6B
Strain, Micro Inches	570	580	580	570	550	540	550	490
Time of Loading Bar, Secs.	1	35	35	35	35	35	1	1
Bar Temperature, degrees F	74	74	74	74	74	74	74	74

Test #28	Application	Test
Date	19 Dec 1947	20 Dec 1947
Time	1600	1000
Wet Bulb	57°F	56°F
Dry Bulb	74°F	72.5°F
#Stresscoat Used	#1205	#1205

Calibration Bar No.	1	2	3	4	5	6	7	8	9	10
Strain, Micro Inches	680	620	630	780	820	850	700	630	620	600
Time of Loading Bar Secs.	30	30	30	30	30	30	30	1	1	1
Bar Temperature, degrees F	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5

Remarks:

Bars #4, #5, #6 were purposely crazed by exposure to cool air and then were allowed to return to room temperature.

The average Stresscoat thickness on each of the ten bars tested was between .0065" and .0075".

Test 12B	Application	Test
Date	19 Dec 1947	20 Dec 1947
Time	1600	1000
Wet Bulb	57°F	56°F
Dry Bulb	74°F	72.5°F
#Stresscoat Used	#1205	#1205

Calibration Bar No.	1	2	3	4	5	6	7	8	9	10
Strain, Micro Inches	680	620	630	780	820	850	700	630	620	600
Time of Loading Bar Secs.	30	30	30	30	30	30	30	1	1	1
Bar Temperature, Degrees F	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5

Remarks:

Bars #4, #5, #6 were purposely crazed by exposure to cool air and then were allowed to return to room temperature.

The average stresscoat thickness on each of the ten bars tested was between .0065" and .0075".

APPENDIX D

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